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Developing Conceptual Models for Assessing Climate Change Impacts to Contaminant Availability in Terrestrial Ecosystems

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INTRODUCTION: The objective of this work was to develop a series of conceptual models (CMs) that illustrate how various aspects of climate change can impact contaminant availability and threatened, endangered, and at-risk species (TER-S) of terrestrial habitats on military installations. The goal was to develop tools that aid installation managers with better managing climate change impacts. The CMs can be used as a framework by military installation natural resource personnel to better delineate impacts of climate change.

As a means of furthering this work, a series of workshops was held with contaminant management, terrestrial vegetation dynamics, and soil/hydrology experts to develop the necessary information to fully inform development of the CMs. During these workshops, a series of specific questions were posed to the experts to gather information about climate change, contaminant availability, and TER-S conservation on installations.

CONCEPTUAL MODEL BACKGROUND: Conceptual models are illustrations created to promote a general understanding of a complex process or system. CMs describe "how the system works" and are flexible tools that are generally project or problem specific. Building a CM includes determining the components of the ecosystem, identifying relationships linking these components, and specifying mechanisms by which components interact. The CM is primarily used for educating and communicating results to sponsors, stakeholders, and other actors, but is also useful for identifying which relationships are likely to be of most importance for the system. CMs have been used by numerous scientists and engineers in the fields of chemical risk assessment (USEPA 1997, 1998; ASTM International 2008; Mayer and Greenberg 2005), effects of dredged material (PIANC 2006), and ecosystem restoration (Fischenich 2008) among others. The process of developing a conceptual model is instructive as it helps identify and understand complex aspects related to climate change impacts on natural terrestrial infrastructure. Furthermore, the process of developing a CM also helps ensure that potentially overlooked elements of the ecosystem are identified and considered. In the context of this research, CMs can demonstrate how climate change can impact terrestrial natural resource management on military installations; they also set a framework for more detailed analysis later.

The CM should: 1) identify the problems and alternatives that should be evaluated early in the project; 2) provide a framework for predicting and generating effects hypotheses; and 3) function as a powerful communication tool to provide an expression of the assumptions and an

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understanding of the ecosystem components potentially affected. The complexity of the CM developed depends on the complexity of the problem and, as such, a CM has the flexibility to include multiple components, multiple mechanisms, and their interactions. However, a level of detail should be maintained that is consistent with the amount of information available used to illustrate each of the main components of the CM. Conceptual models can consist of narratives, tables, matrices of factors, pictures, or box-and-arrow diagrams (Fischenich 2008). The authors combine narrative and box-and-arrow CM types for this research to reduce inherent weaknesses of any single model type.

WORKSHOPS: Three workshops were held on the following topics: contaminants, vegetation, and soil/hydrology. Each workshop was held at ERDC-EL Vicksburg in spring 2013; remote attendees participated via web meeting. Participants of each workshop were selected based on their expertise in the areas of interest. Experts were asked to identify stressors, pathways, and terrestrial receptor information that were subsequently used to construct the CMs. Participants provided answers to questions designed to gather the information necessary to inform the development of CMs in the context of climate change and contaminant management on military installations. The questions posed to experts were the following:

1. What are the most important ecosystem components needing protection?
2. What are the relevant pathways for contaminant migration and transport?
3. What are the key stressors associated with climate change that can impact the ecosystem?
4. What are the mechanisms by which aspect of climate change can impact the ecosystem?
5. What are the things we should measure to understand climate change effects on the ecosystem?

The answers and transient discussions provided by participants were recorded and the results summarized below. While no formal workshop was conducted for TER-S, subject matter experts were contacted and they assisted with CM development.

WORKSHOP RESULTS: This section provides summarized results of the workshop queries from the participating experts for the five questions posed.

What are the most important ecosystem components needing protection?

- Threatened and endangered species (also top-level predators and other keystone species)
- Wetlands
- Grassland/Rangeland plant communities
- Microbial community as related to contaminant movement/breakdown

What are the relevant pathways for contaminant migration and transport?

- Direct and indirect pathways (surface runoff/overland and air transport)
- Water movement through soil horizons and flow/dissolved transport through subsurface soils

- Wildfire-related transport was also discussed as an air transport concern
- Uptake of contaminants in herbivores (indirect transport) and trophic transfer

What are the key stressors associated with climate change that can impact the ecosystem?

- Two categories discussed: Stresses on natural infrastructure and anthropogenic-originated stresses
- Natural infrastructure stresses as indicated by changes in: soil biogeochemistry, fire frequency, erosion, water budgets and cycles, evapotranspiration rates, surface/air transport of particulates
- Anthropogenic stresses: installation training and readiness activities resulting in soil compaction and other physical stressors, pollutants from legacy contaminants as well as emerging contaminants (e.g., nanomaterials), and invasive species/pathogens

What are the mechanisms by which aspects of climate change can impact the ecosystem?

- Change in precipitation and temperature were primarily stressed
- Storm frequency and intensity (extreme weather events)
- Sea-level rise and changes in hydrological cycles

What are the things we should measure to understand climate change effects on the ecosystem?

- Soil variables identified as important measures: soil tilth, nutrients/composition, pH, redox potential, salinity, porosity, permeability, texture, water content, soil organic matter/carbon, and fertility
- Soil parent material and horizons as well as wetting and drying patterns of soils were also described as information necessary to determine surface and subsurface conditions to encapsulate seasonal fluctuations, permanent wilting point, and field capacity

Some parameters discussed were more consistent with potential assessment endpoints, so these items are summarized here. Parameters mentioned that may be important for understanding climate change effects on the terrestrial environment were: community losses/composition, plant species shifts, connectivity/habitat fragmentation, dispersal limitations, linkages between microbes, plants and animals, reproductive strategies, and community stability-disturbance patterns. These parameters were used to identify stressors, measures of effect, and receptors appropriate for this study, as outlined below.

CONCEPTUAL MODELS: The stepwise process reported by Grant et al. (1997) was followed for formulating CMs for this project. This serves as the basis for the CM narratives.

Conceptual Model Objectives. The CM's objective for this research is to illustrate how various aspects of climate change can impact contaminant availability at military installations. CMs will aid installation managers to better manage climate change impacts on installations.

System Boundaries. The focus will be on natural terrestrial infrastructure, especially vegetation shifts in forests, grassland, and range environments. Adjacent wetland and riparian habitats are included, whereas surface water habitats and related sediments are excluded.

Critical Model Components within the System of Interest and Relationships among System Components. There are several critical model components within the terrestrial ecosystems of interest. These critical components are listed and described below in terms of how these components are interrelated.

Primary Source/Stressor: A stressor is any physical, chemical, or biological entity that can induce an adverse response. In the context of this study, the primary stressor is climate change. This primary stressor may adversely affect specific natural resources or entire ecosystems — including animal species and the environment with which they interact — as well as the availability of contaminants generated as a result of military training and readiness.

Secondary Sources/Stressors: Stressors of this type included in the CMs are human induced and act upon supporting components of the ecosystem, which subsequently place stress on the ecological components of interest (receptors). These stressors also included those acting upon supporting components of the ecosystem, which subsequently place stress on the ecological components of interest (natural infrastructure). Examples of secondary stressors include wildfires, floods, and erosion.

Measures of Effect: A measure of effect is a quantitative expression of a response that provides insight into potential climate change effects on the corresponding receptors. Measures of effect are measurements obtained by environmental sampling, modeling, or laboratory testing, which can include a variety of analytical and observational data (e.g., chemical concentrations in surface soil, population density, etc.).

Receptors: Receptors are ecological entities that are exposed to the stressors (in this case chemical contaminants) and are selected based on the potential for these species to be impacted by climate change as it affects contaminant availability in terrestrial environments. Receptors selected for this study were those that met multiple criteria relevant to climate change stress and military installations. Terrestrial TER-S were grouped based on the similarity in life history characteristics. Conceptual models were then developed for each of these species groups to ensure inclusion of a wide range of terrestrial TER-S. Receptors identified as meeting these criteria were terrestrially based bats, reptiles, amphibians, and birds and were therefore used for developing CMs.

Developing Conceptual Models. A CM integrates existing information identifying project-related stressors and their sources, not only in the construction phase, but also in operation and dismantling phases; describes the functional pathways by which these stressors may reach environmental resources of interest; and specifies which resources might be linked to the stressors by these pathways. The CM diagrams, combined with a supporting narrative that describes the links between stressor sources and resources of interest, form the basis for deciding which resources to address. Additionally, the CMs, together with the narratives, help natural resource managers identify the stressors that will be evaluated. In the following sections, the

CMs developed for assessing climate change impacts to various aspects of terrestrial ecosystems are described.

The authors developed six conceptual models for the following topics: contaminant availability, bats, birds, non-bat mammals, reptiles, and amphibians. To maintain consistency in the approach, the same framework was used for all developed CMs (Figure 1-6). These CMs illustrate the climate change-related sources and other external stressors that play an important role in species habitat change or contaminant availability. There are two primary source and stressor categories: fundamental climate change and land management. Sources and stressors associated with climate change include shifts in precipitation and temperature. Land management stressors include factors such as controlled fires, timber harvests, and human disturbance. Stressors related to fundamental climate change can directly impact secondary sources and stressors related to soil characteristics and can indirectly impact natural imbalances and changes to landscape vegetation. Land management stressors can also directly impact landscape changes. These secondary sources and stressors, in turn, affect various aspects of the terrestrial landscape that are quantified by the measures of effect for each secondary source/stressor. There are several measures of effect that can be utilized to quantify climate change impacts related to terrestrial environments, depending on the secondary stressor source. These interrelated measures of each CM examined were quite diverse, but the measures were selected based on the importance of the topic of interest and how vulnerability or availability could be measured. For example, the measures indicated in the contaminant availability CM (Figure 1) identifies microbe activity, invertebrate density and abundance, organic matter, pH, water availability, and cation exchange capacity as key parameters of interest. Once these measures of effect are quantified, the resulting data are compiled to generate individual scores; the compiled data are subsequently used to document both direct and indirect impacts for each secondary stressor. These data are then used to generate an overall summary score documenting and assessing overall climate change impacts to contaminant availability. The CMs were customized to meet the requirements for the species group of interest. Another example of key stressors may be seen in the amphibian CM; water availability is a crucial stressor tied specifically to habitat availability for amphibians due to their need of water for breeding and egg-laying (Figure 4). These measures of effect, as uniquely described in each CM, are suitable measures of impact that natural resource personnel can use to assess terrestrial species of interest or contaminant availability.

SUMMARY: The goals for developing CMs to assess climatic impacts are two-fold. First, development of CMs provides a framework for identifying sources of stressors and where the effects will most likely be exhibited. This allows for the determination of what variables are obtainable and how best they may be used to assess the vulnerability of a specific region or ecosystem of interest. Second, the CMs developed for this research provide an evaluation pathway to determine how climate impacts can be evaluated and how they can be coupled with other measures of effect not directly tied to climate change via a susceptibility analysis.

Specifically, these CM frameworks provide the structure for identifying metrics for assessing and determining the vulnerability of TER-S on military lands to changes in the bioavailability of contaminants due to aspects of climate change. Using this framework, researchers may determine what metrics they need and/or have the ability to measure to determine the risk of future climatic conditions on select terrestrial habitats.

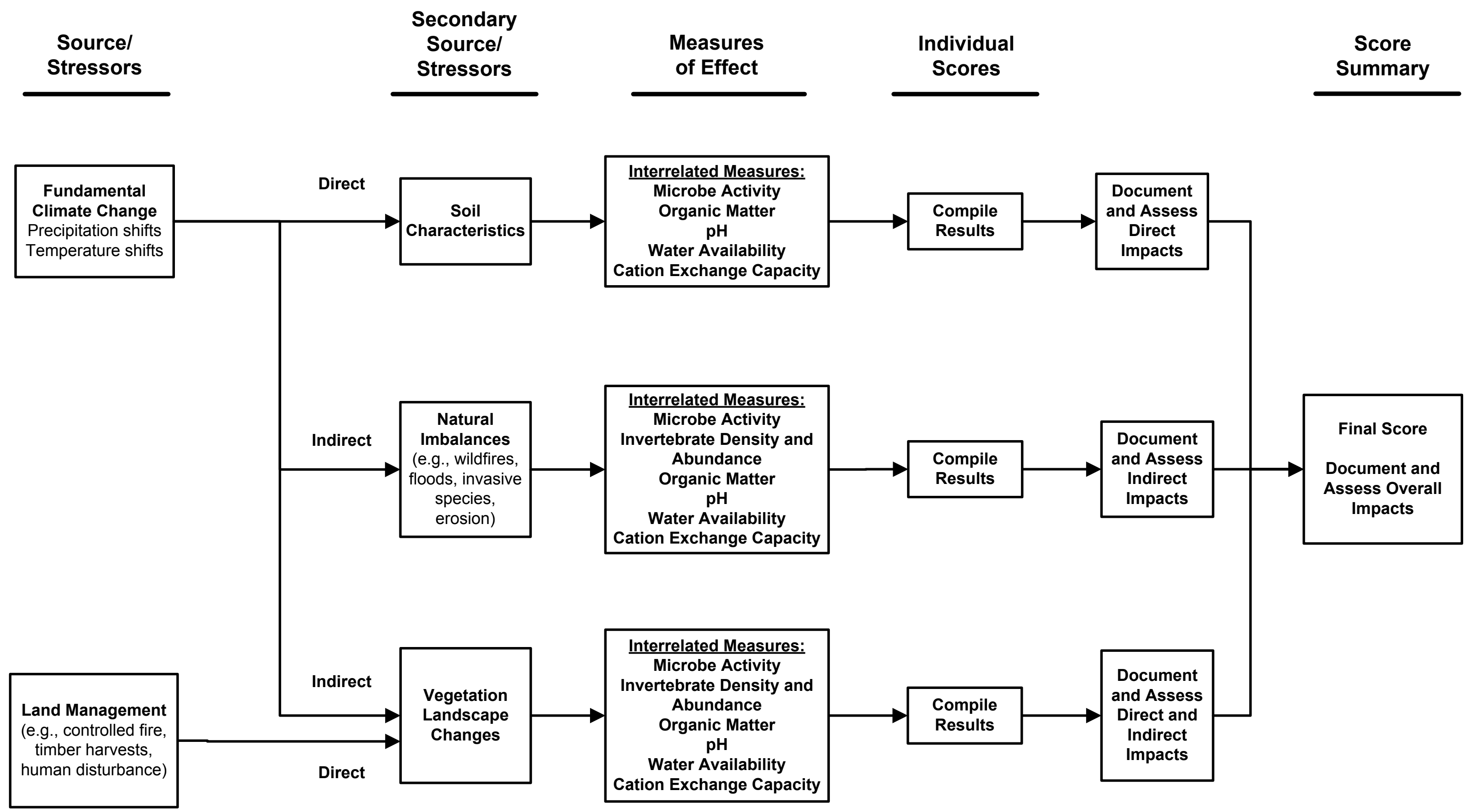

Figure 1. Conceptual model for climate change impacts to contaminant availability at military installations.

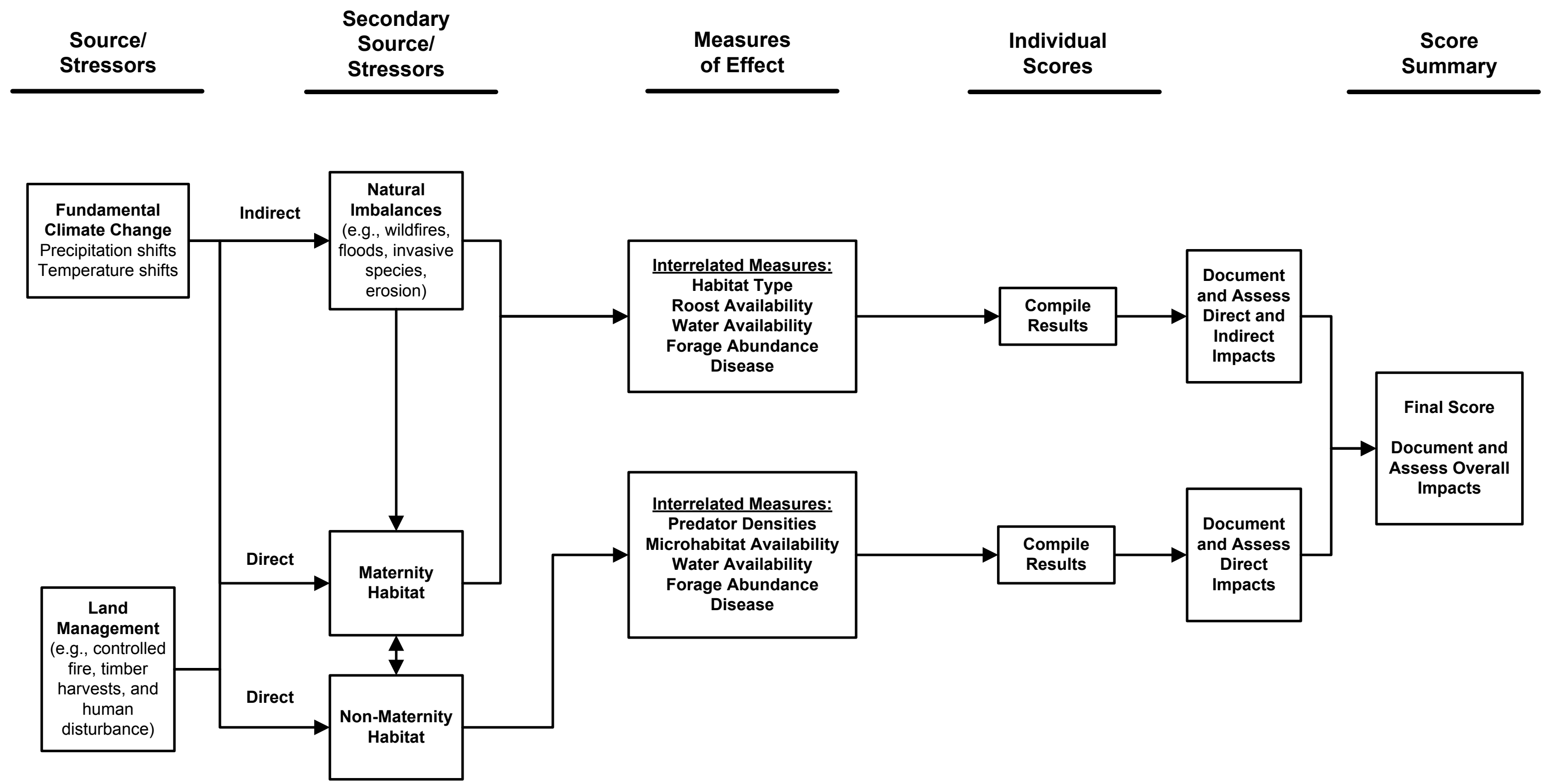

Figure 2. Conceptual model for climate change impacts to bat species at military installations.

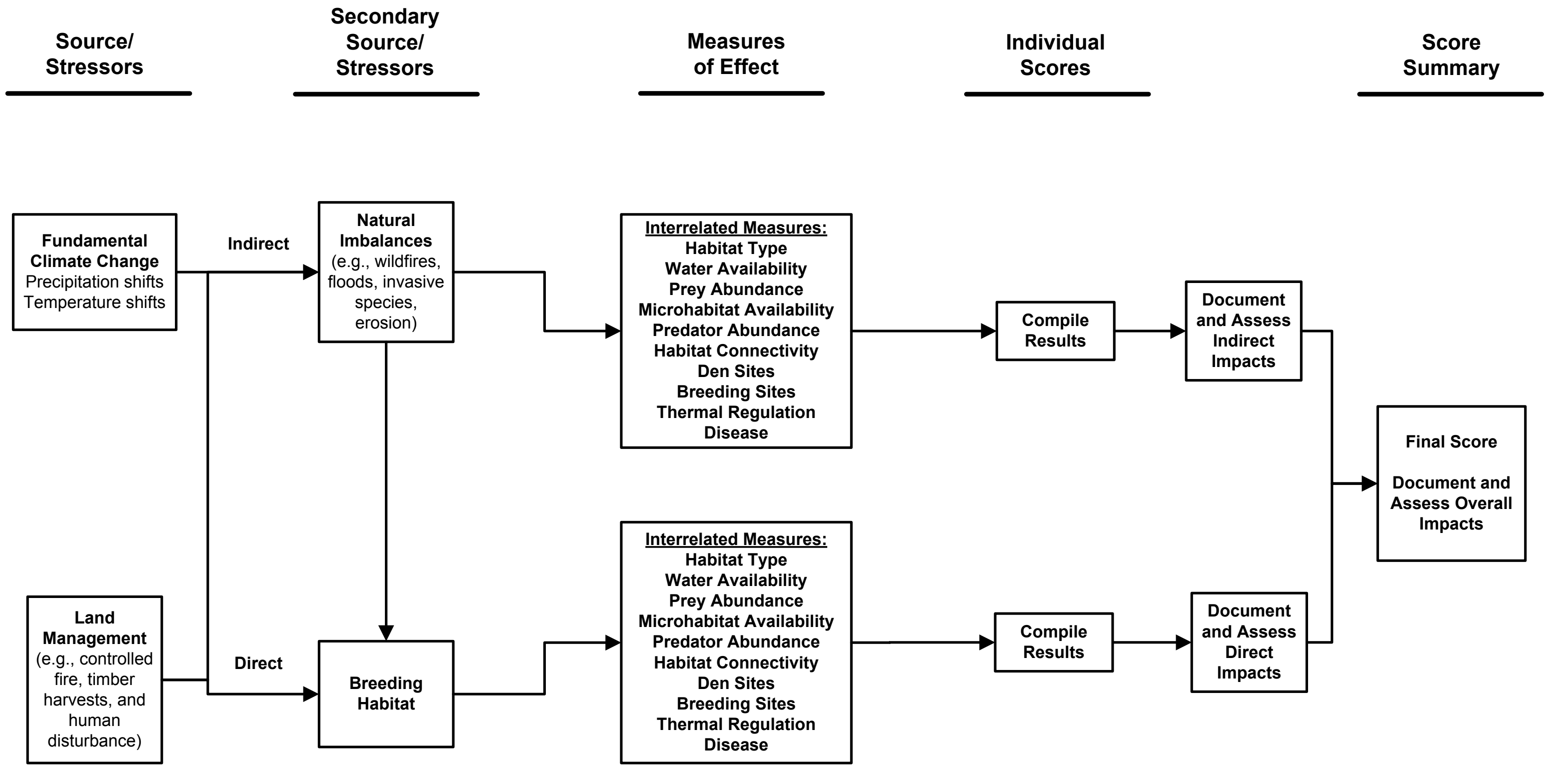

Figure 3. Conceptual model for climate change impacts to terrestrial reptile species at military installations.

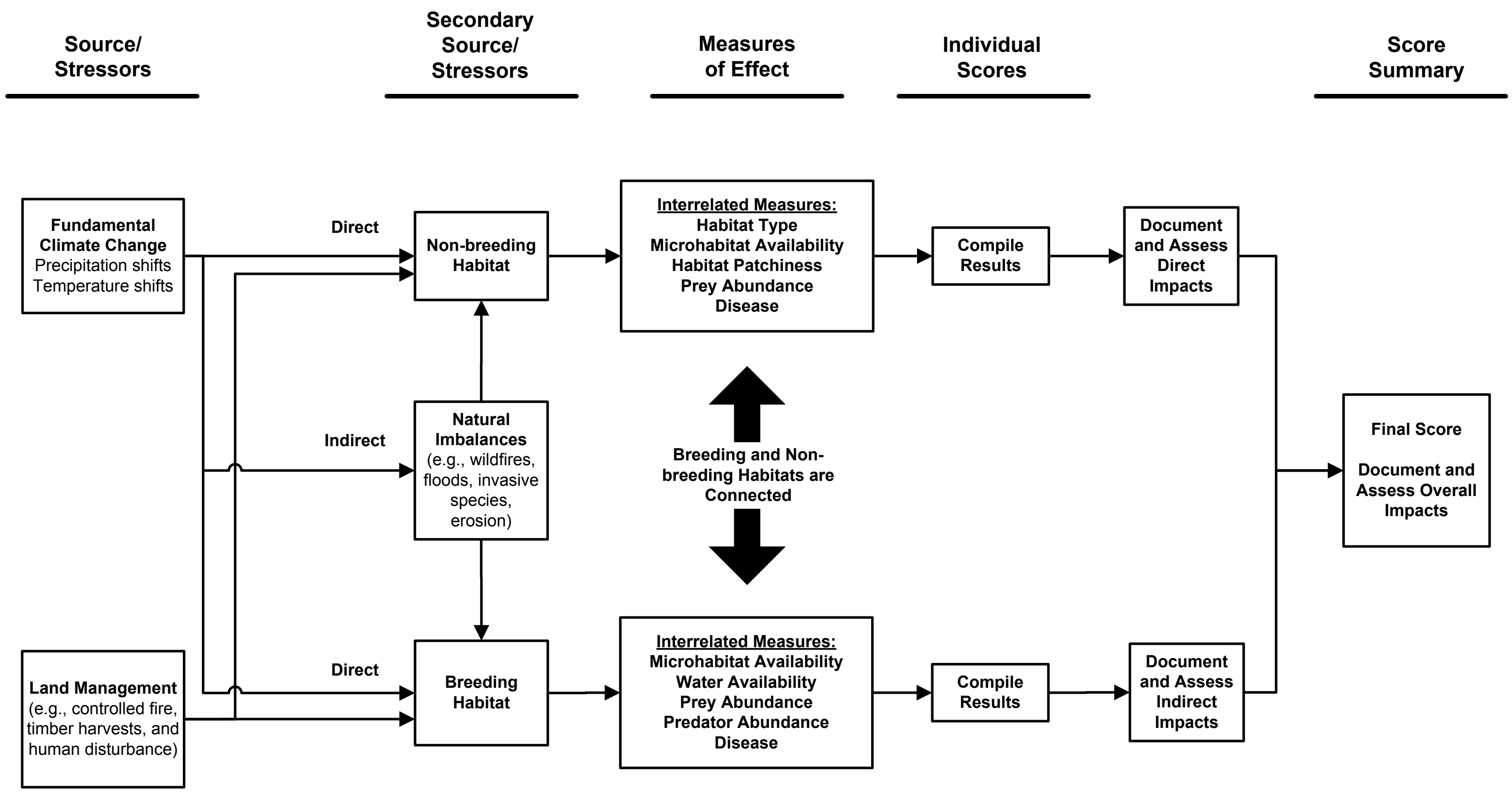

Figure 4. Conceptual model for climate change impacts to terrestrial amphibian species at military installations.

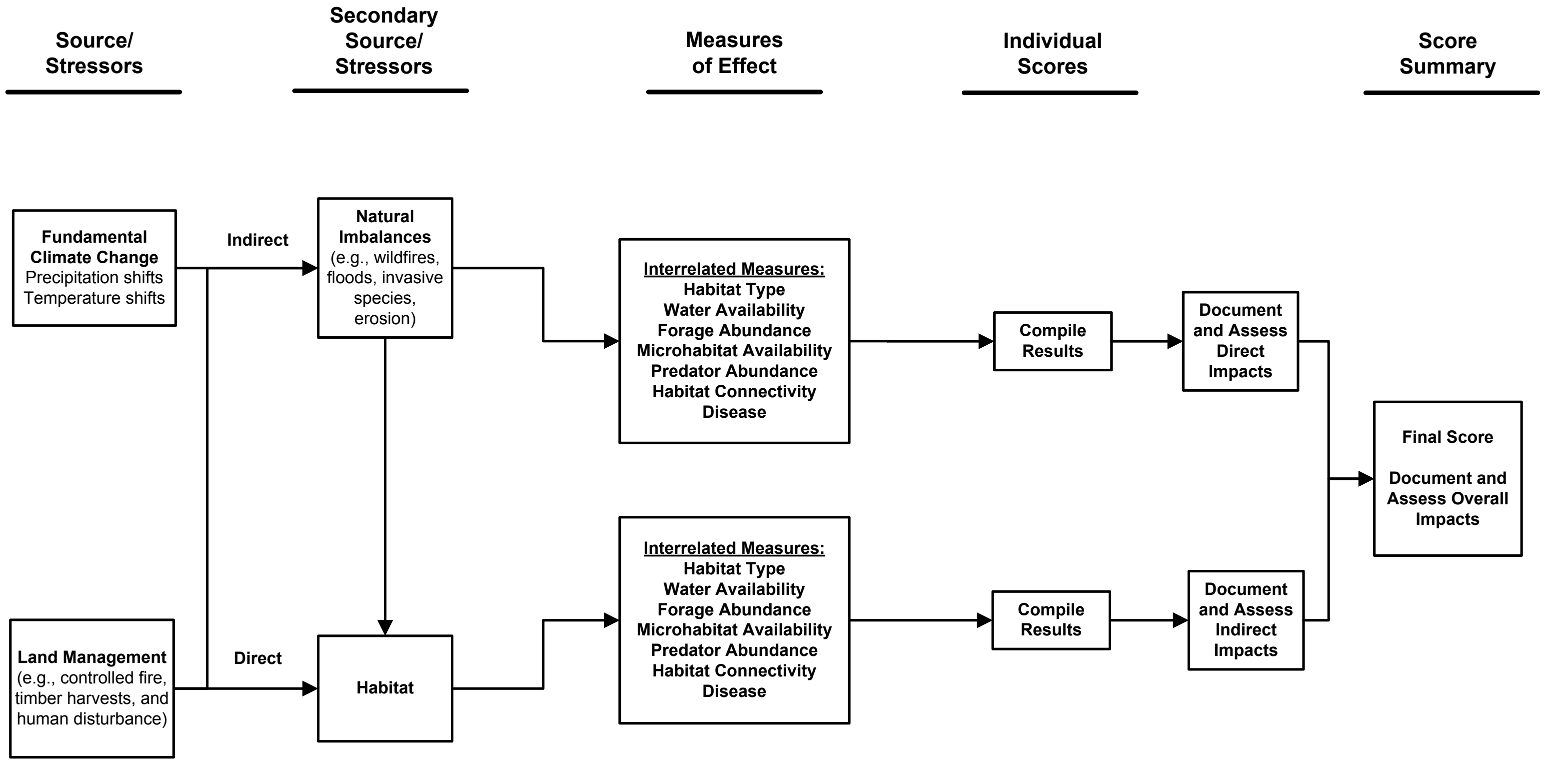

Figure 5. Conceptual model for climate change impacts to terrestrial mammal species at military installations.

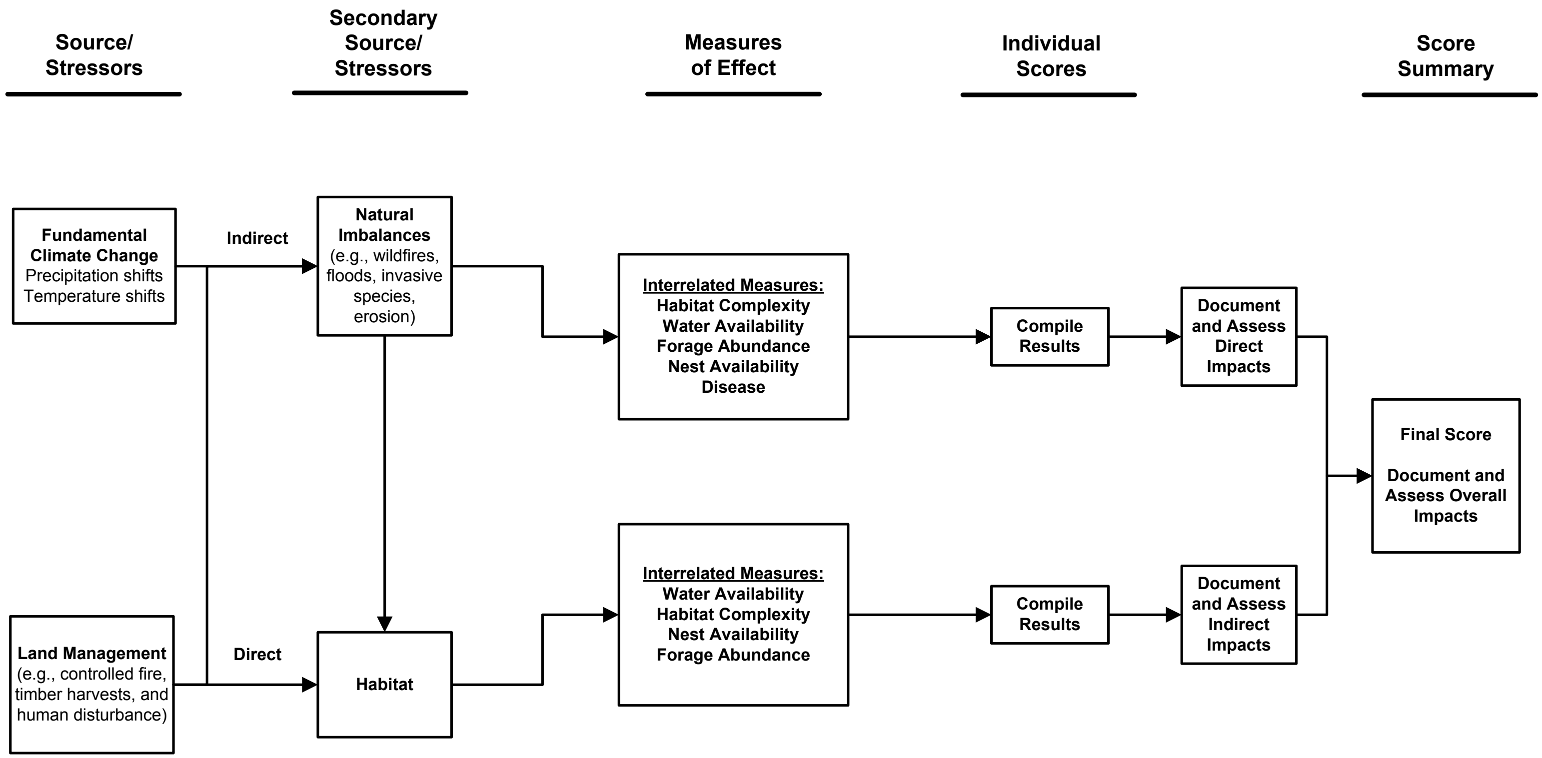

Figure 6. Conceptual model for climate change impacts to terrestrial bird species at military installations.

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